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# Effect of Elevated $Co_2$ and Shading on Growth, Physiological Changes, Yield and Quality of Cherry Tomato (*Solanum Lycopersicum* Var. Cerasiforme) in Tropical Climate

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**Abstract**

Cherry tomato (*Solanum lycopersicum* var. cerasiforme) from family Solanaceae is an important source for vitamins and other minerals. The demand for tomatoes therefore increases due to the changes in the lifestyle of the food intake among ordinary people who are aware of their nutritional intake. Climate change is nevertheless the greatest treat that can reduced the tomato production. Cultivating indoor using greenhouse is one of the solutions to mitigate this problem. The biggest constraint in tropical climate for greenhouse cultivation, however, is solar radiation and temperature. This study was therefore intended to evaluate the growth, physiology, yield and quality of tomato under two systems of greenhouse; Smart Greenhouse (SGS) versus Conventional Greenhouse (CGS) system. Cherry tomato was grown in two greenhouses at three different shading levels of (0, 50 and 70 percent). SGS received around 800 ppm of $CO_2$ while CGS has been designated as control. The experiments with six replications were carried out in nested design. All the data were compared and subjected to Analysis of Variance (ANOVA). As a results, growth, physiology, and tomato yield were reduced due to high temperature inside SGS under elevated $CO_2$. Additionally, high temperature (32-35$^oC$) inhibited the assimilation of photosynthetic carbon. Thus, fruit setting was delayed thereby reducing yield production. Upon enrichment, vapor pressure deficit (VPD) decreased under elevated $CO_2$ and lycopene under shaded area showed 52% and 25% respectively higher compared to CGS. Overall, elevated $CO_2$ in tropical climate inside greenhouse influences temperature increase that have reduced growth performance, physiology, yield and quality of cherry tomato.

**Keywords**: $CO_2$-elevated, Shading, Relative Growth Rate, Physiological Changes

## Introduction

Cherry tomato (*Solanum lycopersicum* var. cerasiforme) is originated from Central and South America. It belongs to the genus Solanum of the family Solanaceae (Benton Jones, 2007). Recently, cherry tomato increasingly popular among common people because of nutrient content which can provide antioxidants, fibre and some vitamins for our body (Carillo *et al*., 2019). Tomato cultivated in the greenhouse has many advantages compared to open fields which can produce higher quality and enhanced yield production (Karim *et al*., 2020). However, poor quality of tomato in term of flavour has been reported in the past few years in China (Baldwin *et al*., 2000; Causse *et al*., 2003). According to previous research, the quality of tomato was influenced by $CO_2$ concentration in the greenhouse (Jin *et al*., 2009). Furthermore, many studies reported that the ideal concentration of $CO_2$ for vegetable cultivation in the greenhouse is 800 – 1000 ppm (Krumbein *et al*., 2006). On the other hand, the concentration of $CO_2$ in 500 to 700 ppm potentially produces a higher yield in tomatoes (Krumbein *et al*., 2006). The supply of higher $CO_2$ concentration during the plant growth increases the sink strength where more carbohydrates shift to fruit development that leads to producing higher yield (Mamatha *et al*., 2014). However, researchers around the world have recently debated the increasing $CO_2$ concentration in the atmosphere leads to increase ambient temperature. In a tropical climate, temperature and solar radiation are the biggest constraints in the greenhouse cultivation. Thus, elevated $CO_2$ in the greenhouse could be attributed to an increment of temperature and humidity that caused disease problems in tomato such as sunscalding and fruit cracking. Hence, shading application is used to reduce light intensities based on plant necessity which can influence microclimate in the greenhouse. Shading was found to improve the appearance of the tomato by a 35% reduction of sunscald and fruit cracking (Kirschbaum, 2011). Similarly, the other study was found shading could increase the marketable yield by 50% compared non-shading cultivation (Ilić *et al*., 2012).

## The objective of this study

**i.** to evaluate the effect of elevated $CO_2$ and shading on the growth, physiology, yield and quality of cherry tomato in the tropical climate.

## Materials and Method

*Experimental Site and Plant Materials*

A cherry tomato cultivar (“Ruby103”, Green Eagles. Malaysia) was grown under two greenhouses at Field 15, University Putra Malaysia, Serdang, Selangor, Malaysia (2.983733, 101.732526) from September to December 2018. Two identical greenhouses (30.5 m length x 6 m width x 3 m height) namely SGS (Smart Greenhouse) and CGS (Conventional Greenhouse) (Figure 1) was installed with four (4) units of exhaust fan (60 kW; 30AQM8, KDK, Japan). Both greenhouses were equipped with data logger (Model: HT-2000, Xintest, China) for monitoring climate changes. However, only SGS was installed with two (2) axial fan (400kW; MSA 400Fq, GTG, Malaysia) and a CO2 gas injection system. CGS was designated as control.

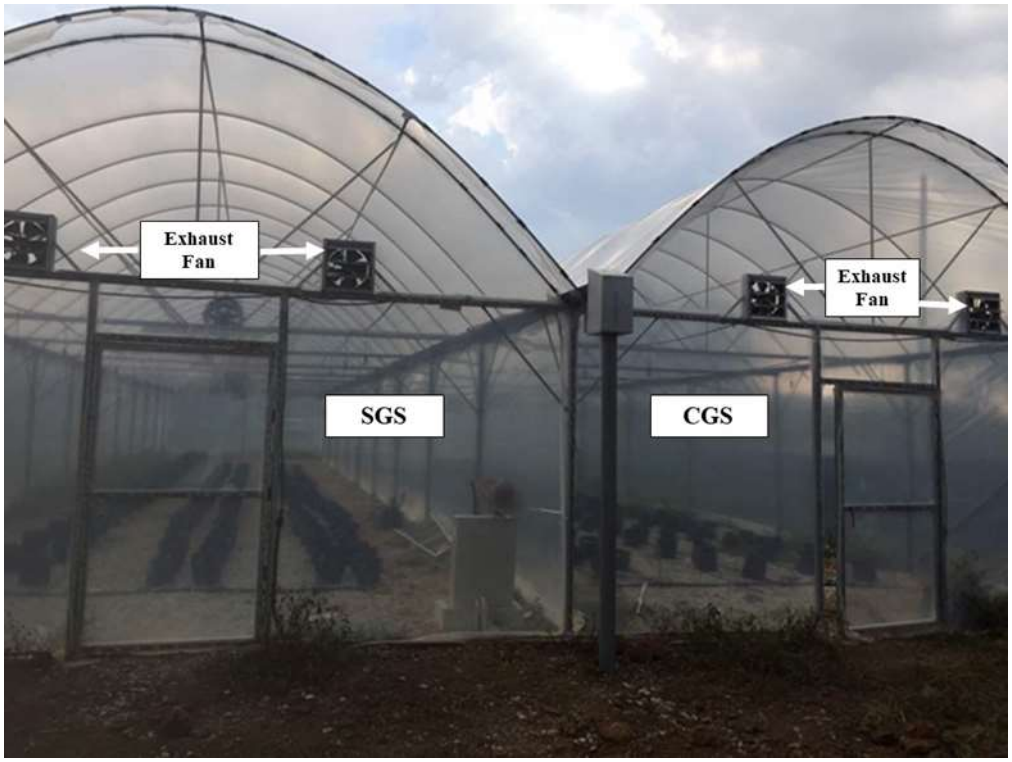



Figure 1. Comparison between SGS and CGS greenhouse system

***Treatments and Plant Maintenance***

The 99.8% purity of $CO_2$ was supplied in SGS at a constant rate (800 ppm) in the morning from 0800 to 1000 while CGS was kept as control (400 ± 50 ppm). The plants were subjected to three different shading levels (0, 50% and 70%) and irrigated using a fertigation system (D25RE2, Dosatron, USA) five (5) times daily (0800, 1030, 1200, 1430 and 1700) using a timer with 1.5 L copper formulation solution as source of fertilizer using fertigation system. Management of pests and diseases were imposed following standard procedures under greenhouse condition.

***Determination of Plant Growth Analysis***

The plant height of cherry tomato was measured from the growth media surface to the tip of the main stem. The total leaf area was determined by using the Automatic Leaf Area Meter (LI-3100, LI-COR, USA). Six (6) plants of each treatment were destructively sampled for dry weight. Leaf (LDM), stem (SDM), root (RDM) and total dry mass (TDM) were recorded after drying in an oven at 60°C for three days or until constant dry mass was obtained. The data was measured at 90 DAT. Specific leaf area (SLA) was determined by dividing the area of harvested leaves with a dry weight of leaves. Net assimilation rate (NAR) measured the rate of dry matter production per unit leaf area. NAR was calculated according to equation 1 and expressed with unit g/cm2/day.

$$NAR = \frac{(W2-W1)(\ln A2-\ln A1)}{(A2-A1)(t2-t1)} \quad \textbf{(1)}$$

Where

W = dry weight of plant (g)

A = leaf area ($cm^2$)

t = time (day)

Relative growth rate (RGR) is used to compare the growth performance of species or the effect of treatments on plants. RGR was calculated according to equation 2 and expressed with unit g/g/day.

$$RGR = \frac{\ln W2 - \ln W1}{t2 - t1} \quad \textbf{(2)}$$

In manner of;
W = dry weight of plants (g)
t = time (day)

***Measurement of Leaf Gas Exchange***

The rate of photosynthesis (Ps), stomatal conductance (Gs), transpiration rate (Ts) and vapour pressure deficit (VPD) were measured by using LI-6400 Portable Photosynthesis System (LICOR, Nebraska, USA). The fully expanded leave was used to measure started in the morning at 0900 to 1100 to avoid error due to diurnal variations.

***Determination of Yield Production***

Tomato fruits were harvested every three days starting from seven (7) weeks after transplant. The cumulative total fresh fruit harvested was summed up at the end of the planting period.

***Determination of Fruit Quality***

The total soluble solids (TSS) was measured for each sample of fruit in three replications using a digital refractometer (PAL-1, Atago Co. Ld., Japan). Lycopene in tomato samples was extracted by hexane: acetone: ethanol (2:1:1) (v/v) mixture (Kittasa *et al*., 2009). The absorbance was read at 503 nm compared with hexane on a spectrophotometer (UV3101 PC, Shimadzu, Japan) according to equation 3 and expressed as µg lycopene/g;

$$\text{Lycopene content} = \frac{(A503 \; x \; 537 \; x \; 2.7)}{(1 \; x \; 172)} \quad \textbf{(3)}$$

in which A503 = absorption at 503 nm, 537 = the molecular weight of lycopene (g/mole), 2.7 = the volume of the hexane layer (ml), 1 = the weight of sample added (g) and 172 = the extinction coefficient for lycopene in hexane ($mM^{-1}$)

***Statistical Analysis***

The data were analyzed using analysis of variance (ANOVA) by Statistical Analysis System (SAS 9.4) in nested design to determine the significant difference between treatment means. Differences between treatments means were compared by using Least Significant Difference (LSD) at $p \leq 0.05$ level.

**Results and Discussion**

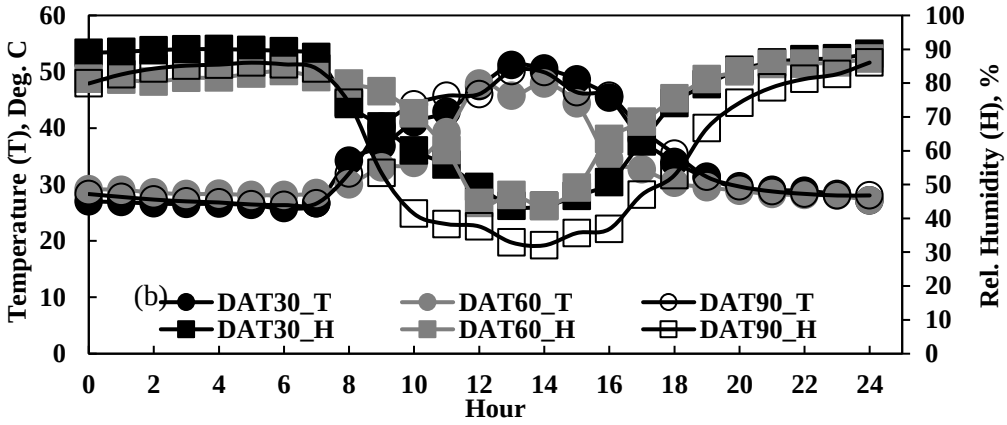
***Greenhouse Environment***

Daily mean temperature and relative humidity were plotted along a 24 hours' axis throughout the planting period in both greenhouses presented in Figure 1. In SGS (Figure 2a), minimum temperature was recorded around 26.4°C while maximum temperature was recorded in the range of 47°C to 51.1°C throughout the planting period (DAT30, 60 and 90). The temperature increased rapidly between 11.00 am to 3.00 pm. Differently from SGS, the temperature in

CGS (Figure 2b) varied from a minimum of 26.2°C to a maximum of 48.5°C around 12.00 to 2.00 pm in DAT30, 60 and 90. However, the ambient environment showed the range of 23.7°C – 33.5°C (Figure 2c).

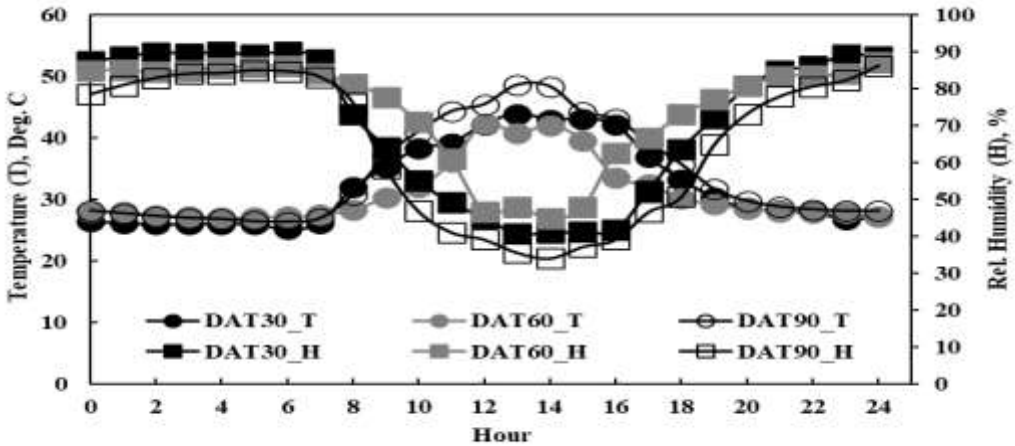
Furthermore, the relative humidity (Figure 1a) showed lower percentage from 12.00 until 3.00 pm (32% in SGS, 34% in CGS and 52.2% in ambient) as equivalent to higher temperature at that times. It was gradually increased after 4.00 pm and all the conditions have similarities.

Figure 3 showed the observation of daily mean $CO_2$ concentration in 24 hours throughout the planting period. The $CO_2$ was elevated in SGS at 800 ppm between 8.00 to 10.00 am resulted the increasing of temperature about 1-2°C compared to CGS (refer Figure 3a). The $CO_2$ enrichment range to fulfill the GH was about 160 – 245 ppm within 10 to 15 minutes. Nonetheless, the $CO_2$ depletion was observed half from the enrichment (8 – 10 ppm/min).




(a)

*(b)*




(c)

*Figure 2. Time course of temperature and relative humidity at (a) SGS (b) CGS and (c) ambient temperature throughout planting period*

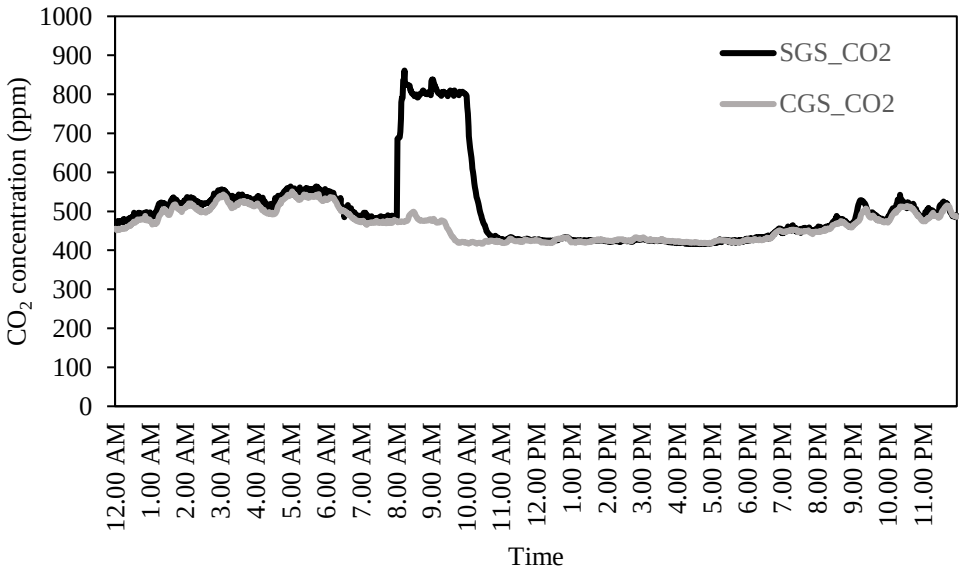



*Figure 3. Example of time course of CO2 supply into SGS throughout planting period*

*Plant Growth*

In the present study, elevated $CO_2$ in SGS had significantly reduced the plant height compared to control ambient in CGS (Table 1). This might be due to an increment of temperature (Figure 2a) in SGS reduced plant height. The previous result reported that the plant height was reduced due to elevated $CO_2$ combined with higher temperatures (Krumbein *et al*., 2006). The maximum plant height was recorded under 70% of the shading level in CGS. However, the lowest plant height was measured under no shading in both greenhouses. In a 70% shading level, the plant has higher availability to absorb photosynthetically active radiation (PAR) resulting in longer internodal length and increased plant height. Similarly, to a previous study that found 75% of shading level recorded higher plant height of cherry tomato (Ordóñez-Santos *et al*., 2011).

The leaf area in CGS showed almost 50% higher compared to SGS under different shading (Table 1). This may be attributed to the high temperature reported throughout the planting period (Figure2a). High temperature decreases leaf expansion resulting in the limitation of the leaf to do photosynthesis. However, in this present study, specific leaf area (SLA) in elevated $CO_2$ higher than control under no shading and 50% shading level while no significant difference recorded under 70% shading level in both greenhouses (Table 1). In relative growth rate (RGR), there were significantly differences between SGS and CGS under all treatments (Table 1). The net assimilation rate (NAR) under SGS were recorded lower than CGS in all treatments. This present study showed that, the effectiveness of elevated $CO_2$ was reduced due to high temperature which is affected the rate of SLA, RGR and NAR. Thus, total biomass under SGS (Figure 3a) was reduced compared to CGS. This present result was found contradict previous research reported that total biomass values in 550 ppm were 10% greater than plants growing in air containing 370 ppm (Argade *et al*., 2018). The higher temperature due to elevated $CO_2$ reduces the development of flower which leads to reduce the fruit production.

*Table 1*
*Effect of shading and greenhouse on plant height (PH), leaf area (LA), specific leaf area (SLA), net assimilation rate (NAR) and relative growth rate (RGR) on cherry tomato after 90 days after transplant. Mean values with the same letter do not significantly difference at (P>0.05) by the least of significance difference (LSD)*

| Shading level | GH | PH (cm) | LA ($cm^2$) | SLA ($cm^2/g$) | NAR ($g/cm^2/day$) | RGR (g/g/day) |
|---|---|---|---|---|---|---|
| 0 | SGS | 136.00b | 1294.48a | 185.14a | 3.33b | 0.051b |
| | CGS | 150.67a | 1422.93a | 102.18b | 8.28a | 0.058a |
| 50 | SGS | 147.67b | 915.40b | 211.91a | 2.59b | 0.039b |
| | CGS | 169.67a | 2340.10a | 155.67b | 4.48a | 0.058a |
| 70 | SGS | 160.67b | 799.80b | 163.97a | 2.84a | 0.04b |
| | CGS | 177.00a | 2985.60a | 167.92a | 2.51b | 0.05a |

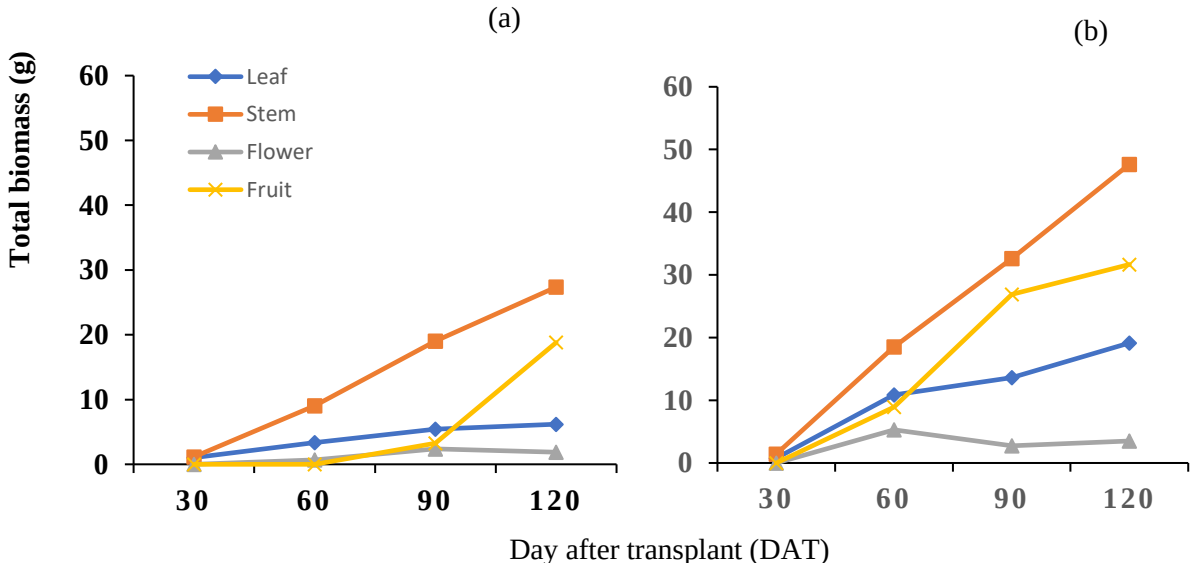



Figure 3: Effect of elevated $CO_2$ (SGS) (a) and control (CGS) (b) on total biomass

***Physiological Changes***

Photosynthesis rate within the different level of shading under both greenhouses was significantly difference as shown in Figure 4a. The result showed plants cultivated under SGS had a higher photosynthesis rate compared to CGS. Photosynthesis rate under elevated $CO_2$ increased Ziska *et al* (2001) due to the increase of efficiency carboxylation to oxygenation, resulting in decreased photorespiration (Thompson *et al*., 2017). Both greenhouses showed noticeable results where the photosynthesis rate was significantly higher at no shading compared to other treatments. Decreases of photosynthesis rate by increasing shading level may attribute to the lower of RuBP carboxylase for carbon fixation through photosynthesis pathway in low light intensity (Reddy *et al*., 2010). Stomatal conductance (Figure 4b) and transpiration rate (Figure 4c) showed a similar pattern in both greenhouses. Theoretically, decreases in stomatal conductance, the transpiration rate also decreases to avoid water loss

(Li *et al*., 2013). The response of stomatal conductance towards $CO_2$ was suggested regarding the malate synthesis which plays important role in anion regulation in the guard cell to the membrane (Kang *et al*., 2009). The result of the vapor pressure deficit (VPD) within greenhouses showed significantly different as shown in Figure 4d. SGS recorded lower VPD than CGS. The low VPD under elevated $CO_2$ gives beneficial to the photosynthesis process which could prevent RuBP oxidation and reduce $CO_2$ in photorespiration (Drake *et al*., 1997).

**Yield Production and Quality**

The yield production was significantly influenced by different shading levels and greenhouses as shown in Figure 5a. CGS showed 28%, 25% and 20% higher yield per plant in no shading, 50% shading and 70% shading level than SGS respectively. It might be due to elevated $CO_2$ in the greenhouse raised the temperature. Thus, inhibited flowering, disturbed fruit development and reduced total yield of production. The reason might be 70% shading level has lower solar radiation which give an impact on fruit yield and quality. These results are consistent with data obtained by a previous study where lower solar radiation under gray shade decreased the number of fruits per plant of tomato (Jiao *et al*., 2019).

Fruit decreased with increased temperature (Lokesha *et al*., 2019). All these studies are consistent with the results obtained in tomato fruit. Lycopene content in fruit on different shading levels within greenhouses was recorded in Figure 4b. The highest lycopene was recorded under a 50% shading level in SGS. In CGS, no shading treatment obtained 33% higher while reduced to 52% in shading level compared to SGS. However, in both greenhouses, lycopene content was reduced in 70% shading level. In this study, the high temperature in SGS helps to increase lycopene content. However, lycopene content will inhibit at a temperature above 32$^{o}$C (Shivashankara *et al*., 2014).

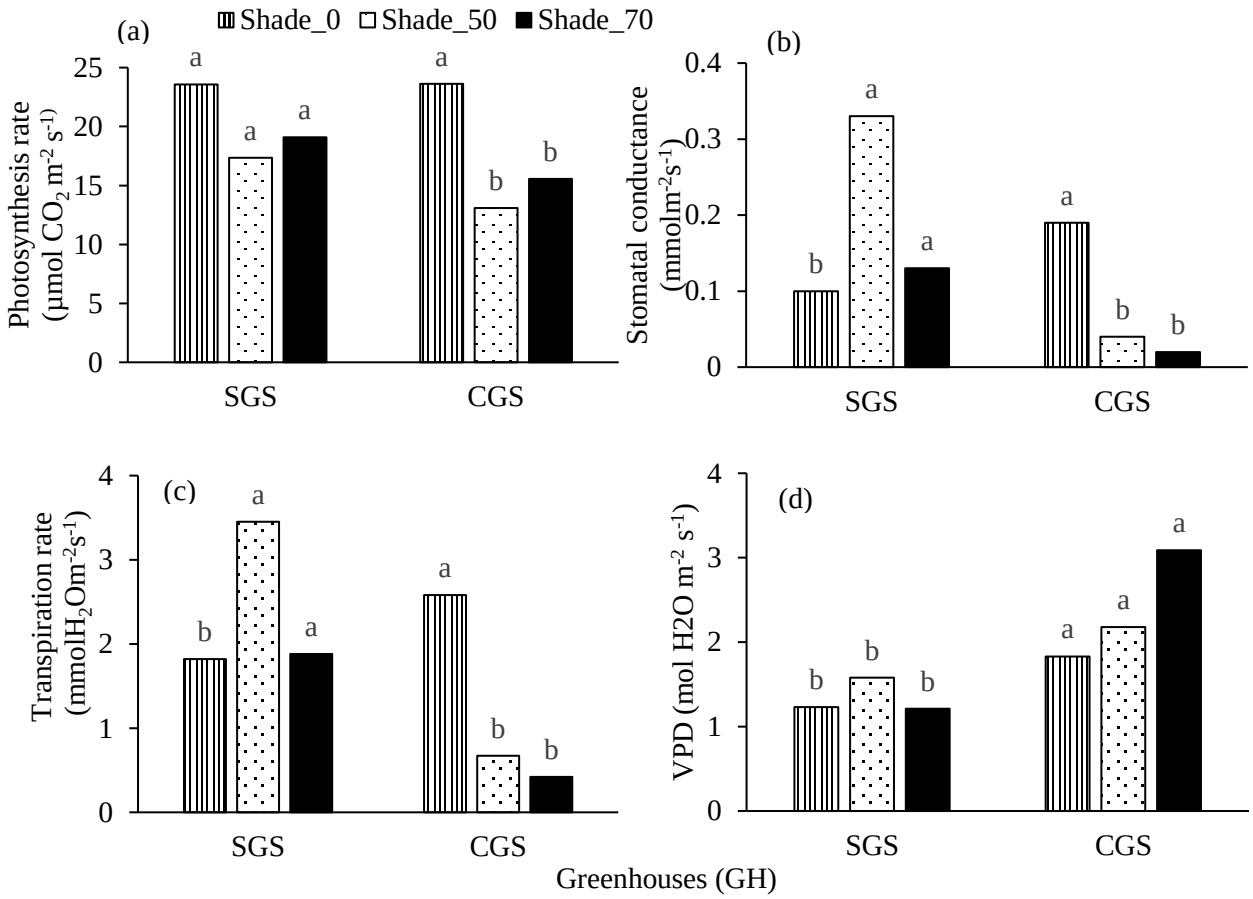



*Figure 4. (a) Photosynthesis rate, (b) Stomatal conductance, (c) Transpiration rate and (d) vapor pressure deficit (VPD) in different shading levels under both greenhouses. Mean values with the same letter are not significantly different at (P>0.05) by the least significant difference (LSD).*

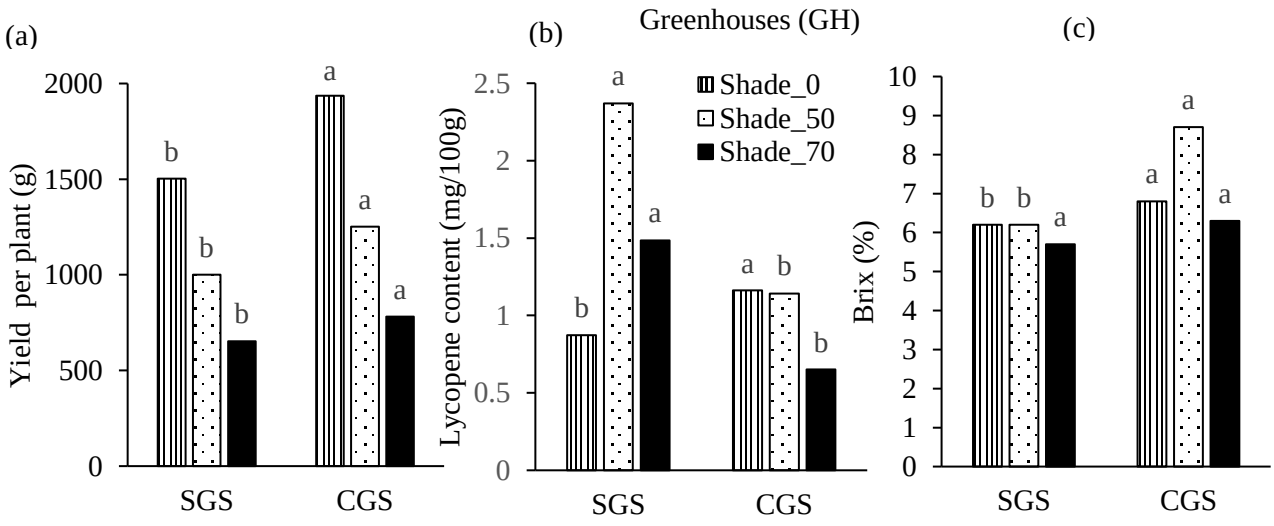



*Figure 5. (a) Yield production, (b) lycopene content and (c) total soluble solids (brix) in different shading levels and greenhouses. Mean values with the same letter are not significantly different at (P>0.05) by the least significant difference (LSD).*

*Significant differences in TSS were observed in response to greenhouses and shading as shown in Figure 5c. Fruits grown under 50% shading in CGS recorded significantly higher TSS than others. Although no shading treatment in CGS showed 40% higher than those grown under no shading in SGS, 50% shading in SGS and 70% shading in CGS, there were no significant difference recorded. The minimum TSS was obtained under 70% shading in SGS. It was due to higher shading level decreased sugar content of tomato fruit (Kirschbaum, 2011). The high temperature was well known to influence fruit maturity and growth (Gama et al., 2017). Besides, a previous study reported total sugar content in five genotypes of tomato.*

**Conclusion**

This study conclude that normal $CO_2$ concentration showed better growth in term of plant height, leaf area and yield production compared with plant cultivated under short elevated $CO_2$ in SGS. Without shading (100% light intensity) indicated high yield production simultaneously with high photosynthesis rate. The result contradicts with previous result due to the microclimate changes inside SGS after $CO_2$ elevation. Increase the $CO_2$ concentration inside the greenhouse is generally conflict with the need to ventilate especially in tropical climate thus cause temperature to increase up to 1-2°C, which create in conducive environment for better performance of red cherry tomato.

**Research Contributions**

This study contributes to evaluate the implement of $CO_2$ enhancement in greenhouse towards the growth, physiology, yield and quality of plants especially in horticulture. In addition, this study was designed to understand the microclimate requirement of the plant inside the greenhouse with $CO_2$ enhancement especially in tropical climate.

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